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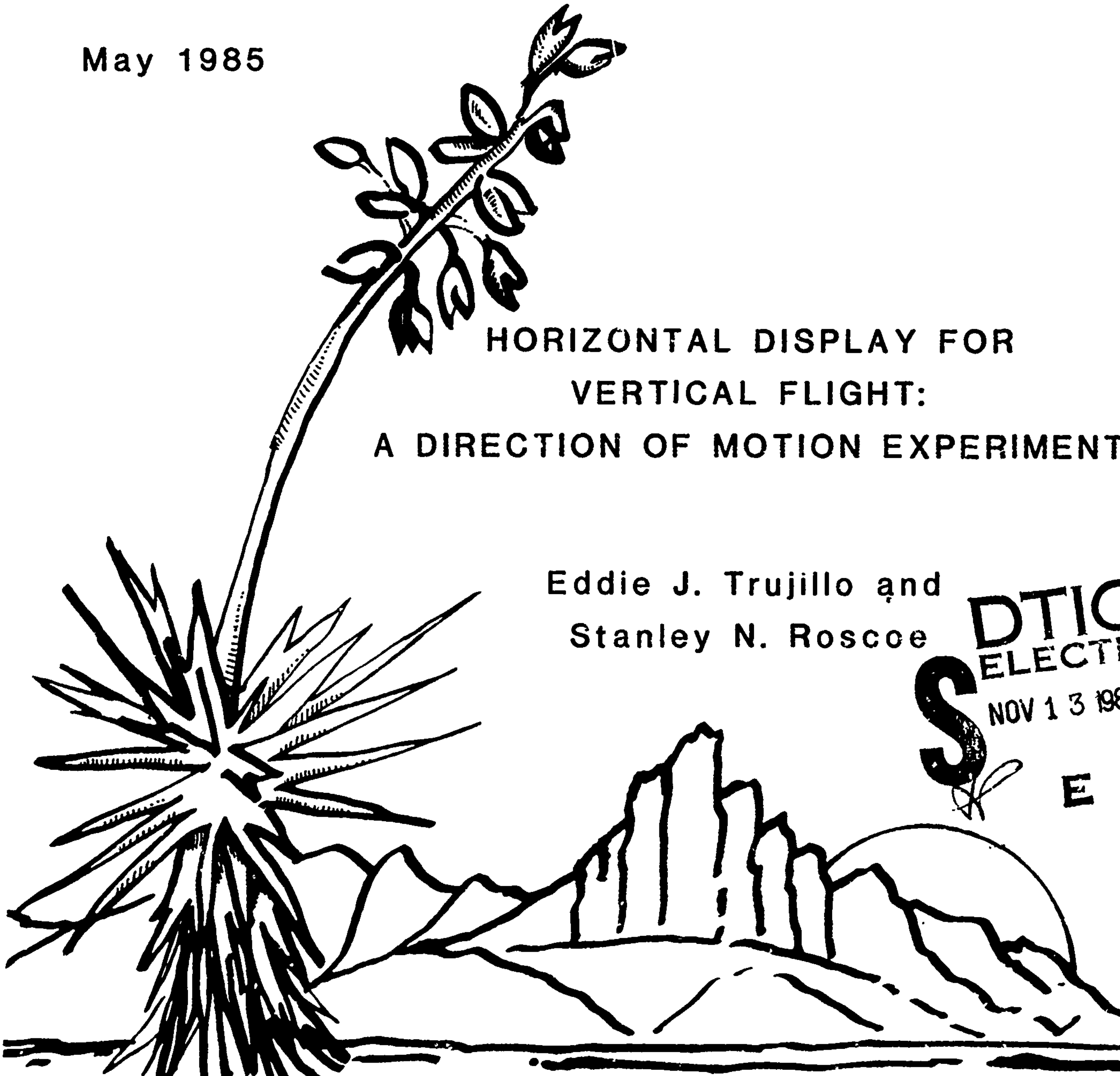

# HORIZONTAL DISPLAY FOR VERTICAL FLIGHT: A DIRECTION OF MOTION EXPERIMENT


Eddie J. Trujillo and
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As a part of a research program to investigate advanced concepts for downward- and forward-looking integrated displays, an experiment was conducted to determine optimum direction-of-motion relationships for a new way of presenting altitude and vertical rate information superposed on a downward-looking navigation and tactical situation display. Altitude was represented by the size of an octagon that could either dilate or constrict to indicate increasing altitude, and vertical rate was indicated by the outward or inward flow of four rate-field patterns emanating from

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) the center of the display toward the 45-, 135- 225-, and 315-degree compass positions. The five factors in this experiment were altimeter and vertical rate-field direction of motion, subject ability level, aircraft vertical control order, and vertical flight course. Performance on four vertical flight profiles indicated that the "out is up" relationship yields superior vertical control, both in terms of control reversals and log RMS tracking precision, whereas the "out is down" mode results in more accurate control in the horizontal plane. The most clearcut finding was that, whichever direction of altimeter motion is adopted, the vertical rate-field motion should be in the same direction.

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# INTRODUCTION

## Context

Vertical takeoff and landing (VTOL) aircraft have not reached their operational potential during all-weather instrument flight. A portion of this problem can be attributed to the inherent instability of the VTOLs' current control systems, while the remainder of the problem is due to inadequate flight displays.

Among the design issues that have to be resolved is how to achieve directional compatibility between control movements and the immediately resulting display indications. Compatible motion relationships are critical not only to the precision of continuous control but also to the prevention of control reversals, displacing a control in the wrong direction because the movement of a display element is misinterpreted. Most people expect moving display elements to represent their own movements. In some cases these expectancies are so universal that they have been termed "population stereotypes."

When control-display arrangements conform to population stereotypes, reaction times are shorter, there are fewer control reversals, control movements are more precise, and the operator can learn to operate a system faster. Humans are remarkably adaptable creatures that can learn to operate a control-display system that requires control movements in directions opposite to those expected. The problem arises when a situation occurs that requires extremely fast reactions. When this happens, learned habits often break down, and the operator reverts to more stereotypic responses.

The display designer must consider the pilot's "frame of reference" when choosing between two possible coordinate systems in which display symbology can move. The designer should determine whether the pilot regards the display as representing the external world moving against the vehicle's reference axes or the vehicle moving against the geographic coordinates of the external world. With respect to motion compatibility, display symbology may move either in the same direction or in the direction opposite to the control input, depending on whether the pilot's frame of reference is the actual or desired position of the aircraft.

Problems such as these are being addressed in a program at New Mexico State University's Behavioral Engineering Laboratory (BEL) for the US Office of Naval Research (ONR) and the Naval Air Development Center (NADC). A major product of this effort is a horizontal display for vertical and translational flight control under all-weather operational conditions (Roscoe, Hull, Simon, and Corl, 1981; Roscoe, 1982; Tatro, Corl, and Roscoe, 1983; Tatro and Roscoe, 1985). The display presents HOrizontally and VERtically INteGrated flight control and navigation information (hence, the HOVERING display).

This research is concerned with the mutually compatible integration of several individually developed and validated flight display and control design principles. Some of these so-called "principles" have found limited application in operational systems. More often system designers have not availed themselves of the known advantages of such features as reduced orders of control, flight-path prediction, display frequency separation, pursuit as opposed to compensatory control arrangements, compatible motion, and dynamically adaptive control/display sensitivity logic. Evidently they have perceived such features as too costly and risky with conventional electromechanical display and control technology.

Despite these limitations, throughout the 1970s ONR, in anticipation of technological advances, supported research on advanced display concepts at the University of Illinois, and now ONR and NADC are supporting a program at New Mexico State to put together all the good old ideas that were once impractical in a systematic way for potential application to helicopters and vectored-thrust VTOL aircraft. Our present problem with VTOL airplanes and helicopters is how to take better advantage of their ability to fly missions totally beyond the capabilities of fixed-wing airplanes, and to do so in bad weather and at night.

One objective of this research is to develop a multiple-regression model of helicopter and VTOL pilot performance as a function of a large number of critical real-world variables, including mission-relevant task variables, display configuration variables, and display dynamics variables for aircraft having variable control dynamics (Tatro and Roscoe, 1985; Wiedemann and Roscoe, 1985). The resulting generalizable display design principles will provide guidance applicable to aircraft capable of vertical as well as translational flight with a high degree of maneuvering independence in six degrees of freedom.

Through the application of several basic display principles coupled with a considerable increase in control augmentation, the HOVERING display represents a positive step toward all-weather flight capability in VTOL aircraft. With integrated, easily interpreted information concerning the positions of relevant aspects of the external environment, projections of present performance, and magnified indications of deviations from the desired instantaneous position, the pilot is able to perform hovering and translational tasks safely and effectively.

## Background

A conceptual analysis and review of instrument flight problems in piloting VTOL aircraft, including helicopters, preceded the development of a generic VTOL simulation and the initiation of an experimental investigation of critical design variables in forward- and sideward-looking vertical situation displays and downward-looking horizontal situation displays (Figure 1). The vertical displays themselves are large, flat, transparent plasma screens on which computer-animated contact analog symbology is presented in real time, and in the case of the downward-looking display, altitude and vertical rate information are effectively integrated with horizontal positions and rates to achieve accuracy and stability of vertical and translational flight control.

In the BEL MicroGraphic VTOL Simulator, alongcourse and crosscourse translational rates and/or accelerations (depending on the mode in effect) are controlled by a three-axis, spring-centered control stick mounted on the right-hand arm rest. Alongcourse tracking is controlled by fore and aft stick displacement from a center detent, and crosscourse tracking by left and right stick displacement. Rotating (twisting) the stick about its vertical axis controls the vehicle's yaw (crab) angle relative to the horizontal velocity vector.

The vehicle's heading in the horizontal plane is displayed by a rotating compass rose that responds to both crosscourse control inputs and weather-vaning of the vehicle due to the effects of relative wind (Figure 2). A turn-rate index line is shown relative to top-dead-center of the display so that a desired heading can be captured by matching this index with the desired position on the rotating compass rose. Crosscourse and alongcourse rates and/or accelerations are displayed by a position predictor.

Vertical flight is regulated by a vertical speed control operated by the pilot's left hand. The vertical speed control is spring-centered and viscously damped and is operated by displacing the stick upward to ascend and downward to descend, similar to a collective control in a helicopter. For vertical flight control, the information provided by the HOVERING display includes a present altitude indicator with an imminent altitude predictor, desired altitude goal bars, and both desired and actual vertical rate indicators (Figure 3).

The present altitude indicator is an octagonal box that dilates as altitude increases and constricts as altitude decreases. Altitude (size of the octagonal box) is read against a fixed scale emanating from the center of the display left and right to the momentary limits of the scale at the display's outer edge. The scale limits automatically change by a ratio of 4 to 1 as the simulated aircraft ascends through the momentary limits and as it decends within the limits of the next larger scale. Altitude goal bars provide an indication of instantaneous desired altitude. The pilot's task is to keep the octagonal box aligned within the altitude goal bars. The altitude goal bars and the octagonal altimeter move independently; hence, altitude control reduces to a basic pursuit tracking task.

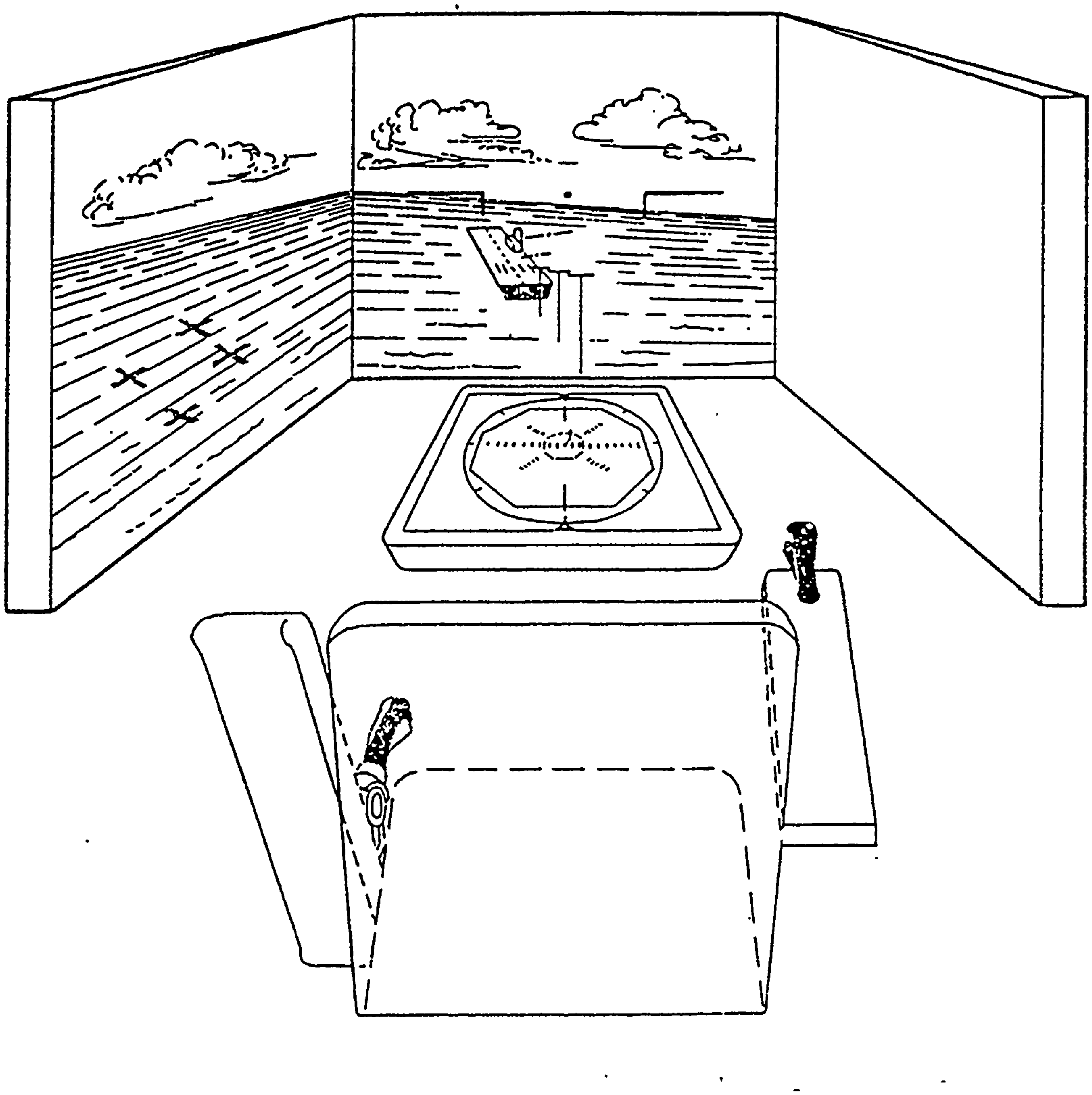

Figure 1. Configuration of BEL's MicroGraphic VTOL simulator, including the centrally located HOVERING display (Tatro, et al., 1983).

Desired vertical rate-field indicators consist of four sets of bars that flow outward to display desired rate of climb and inward for desired rate of descent. The actual vertical rate indicators consist of four sets of bars superposed on, but perpendicular to, the desired vertical rate-field indicators. The flow of both the desired and actual vertical rate indicators matches that of the octagonal altimeter; outward flow indicates a desired or actual rate of climb, and inward movement indicates desired or actual rate of descent. However, there is some question whether the movement of the octagonal altimeter is in the appropriate direction for proper display/control motion compatibility.

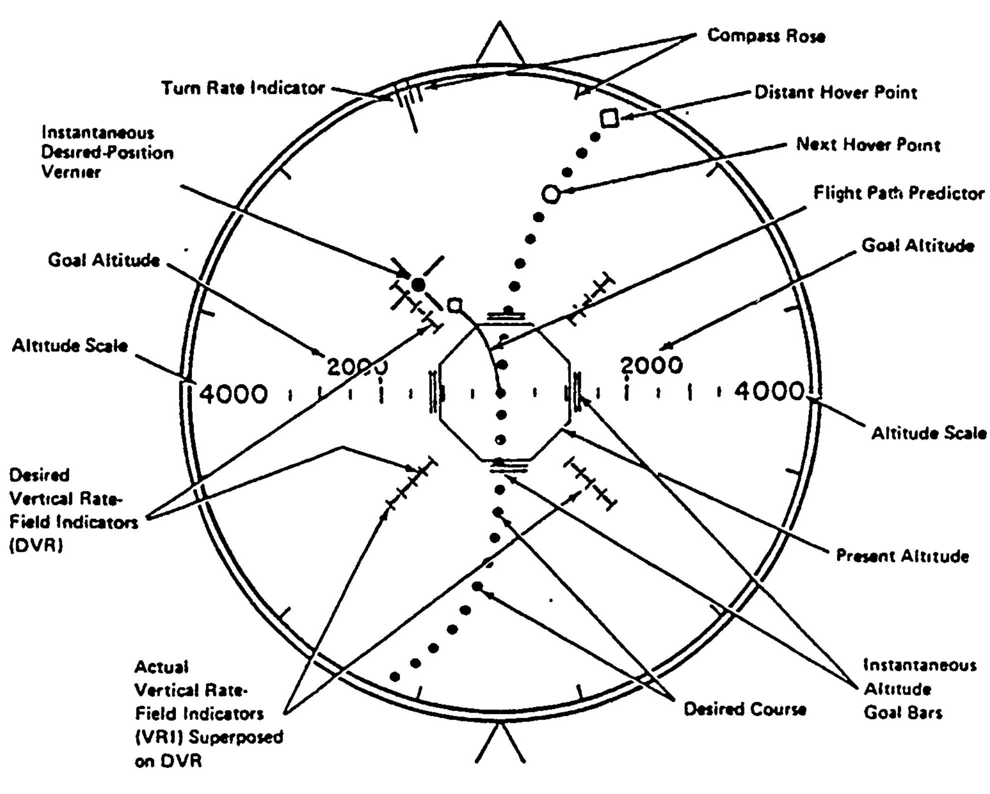


Figure 2. Current configuration of the HOVERING display (Tatro et al., 1983).

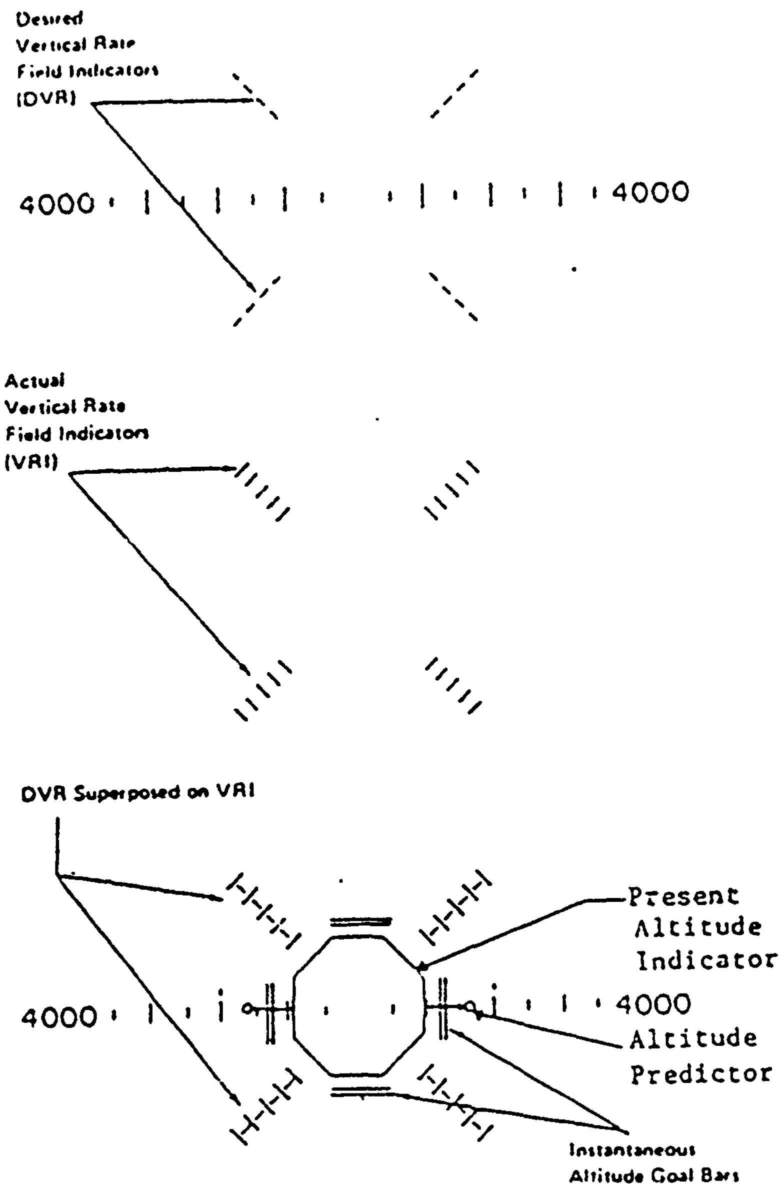


Figure 3. Vertical flight information provided by the HOVERING display.

## Experimental Question

Some engineering psychologists and pilots have suggested that the HOVERING display's presentation of altitude moves in the opposite direction to a pilot's expectation (recall that the octagonal box dilates to show climb and constricts to indicate descent). For example, if a pilot were looking through the floor of his aircraft, then objects on the ground would expand as the aircraft descends. Similarly, as a pilot ascends from liftoff, the scene constricts in terms of the absolute visual angles subtended by surface objects. If one were to apply this analogy to the HOVERING display, then the octagonal box should appear to shrink or constrict as one ascends, and it should appear to grow or dilate during descent (opposite to the display's current configuration).

However, there is an alternative argument in support of the present arrangement that is based on the so-called "principle of the moving part" (Roscoe, 1968a, 1980). This principle refers to the notion that the direction that a display symbol moves should match the pilot's internal representation of that movement. The general rule is this: The part of the display that moves should represent whatever it is that the pilot perceives to be moving in response to a control input; normally it is the airplane. In the simplest case, movement of a control in a specific direction is expected to affect display symbology in the same plane and direction as the control movement (Fitts and Seeger, 1953; Holding, 1957).

In the case of the HOVERING display, one can think of its octagonal altitude indicator as a downward-looking "porthole" through which the pilot can see an increasing area below as the aircraft rises and a decreasing area as it descends. Viewed in this way, the "moving part" (actually the size of the octagonal altitude symbol) increases with altitude, and in this context its "motion" is consistent with the pilot's internal representation of up and down. Which direction of motion is more consistent with the pilot's internal representation of the consequences of his control movements is, of course, the question to be answered whenever a display is designed.

Thus the question of whether the pilot views the display as representing the vehicle moving against the external world or the external world moving against the vehicle must be decided when determining the preferred motion relationships among display symbols and their real-world counterparts. The designer must also consider the possibility that figure and ground relationships between the aircraft and the outside world might change when attention shifts from the outside world to the display inside the cockpit.

Most research on direction of motion compatibility has been restricted to attitude presentation (see especially Bauerschmidt and Roscoe, 1960; Roscoe, 1968b; Johnson and Roscoe, 1972; Roscoe and Williges, 1975; Ince, Williges, and Roscoe, 1975; Beringer, Williges, and Roscoe, 1975; Roscoe, Corl, and Jensen, 1981; Roscoe and Jensen, 1981) to map-type navigation displays (Roscoe, Smith, Johnson, Dittman, and Williams, 1950; Williams and Roscoe, 1950; Payne, 1952; Roscoe, 1968a, 1968b); and to rotary controls and rotary dials (Warrick, 1947; Bradley, 1954; Chapanis and Kinkade, 1972).

Attitude presentation. With respect to motion compatibility in attitude presentation, Roscoe and Williges and their students conducted a series of simulation and flight experiments to compare displays in which either the aircraft, horizon, or both (frequency-separated) moved relative to display coordinates. The results indicate that nonpilots and pilots with little experience can easily learn to use the frequency-separated display. These subjects showed only a small tendency to make the control reversals that inexperienced pilots are subject to on conventional moving horizon attitude displays. Highly experienced pilots readily adapt to the frequency-separated presentation.

Map-type navigation displays. In map-type pictorial navigation displays, position and heading of the aircraft are shown relative to a map of the area. By integrating several separate symbolic cockpit indicators, fewer transformations are required by the pilot to interpret the display's indications. An investigation by Roscoe et al. (1950) showed that map-type navigation displays are superior to separate indicators. A direction of motion question associated with heading on map-type displays is: Should the compass rose rotate against a fixed lubber line so that heading can always be read at the top of the display, or should a pointer rotate relative to a fixed compass rose so that display movement is clockwise when the aircraft is turning to the right and vice versa?

Payne (1952) experimentally compared a fixed, north-up frame of reference with the aircraft rotating and translating relative to the map, versus the map rotating and translating relative to a fixed aircraft symbol always heading up. Results of this investigation suggest that a map-type navigation display should have a symbol representing the aircraft move over a fixed map with the heading shown on the aircraft symbol (e.g., an arrow). At least a portion of the flight path would be shown on the fixed map and the entire display could be manually rotated so that the aircraft symbol could be made to fly on an "up" heading. Roscoe (1968a, 1968b) eventually concluded that the issue is task dependent and that either frame of reference should be selectable.

Rotary knobs and dials. A generally accepted principle for movement relationships of rotary controls and associated displays in the same plane is that a clockwise turn of a control device should be associated with increasing values, although there are some exceptions, such as with a moving pointer on a fixed horizontal or vertical scale with a rotary control beside the scale. In this arrangement the most compatible relationship is that in which the display indicator moves in the same direction as the side of the control knob that is nearest to the indicator (Warrick, 1947).

Bradley (1954) reasoned that several desirable features in a control/display system with a moving scale and a fixed pointer are mutually incompatible: The scale should rotate in the same direction as the control knob (direct drive); the scale values should increase from left to right; and the control should turn clockwise to increase settings. However, all three desirable features are not simultaneously possible. I pending on the system, the best subset can be incorporated. If there are different kinds of compatibility involved in a situation, it may be important to know what type of compatibility is most critical to resolve the conflict in design.

Some control devices are in a different plane from that of the associated display. In a study by Holding (1957) in which the knob and scale were in different planes, rotation of a control knob caused a pointer to move along a straight-line scale. The results indicate that subjects' responses tend to be of two types: 1) a generalized clockwise tendency; and 2) a helical, or screw-like tendency in which clockwise rotation is associated with mover ent away from the individual, and counterclockwise is associated with movement toward the individual (as with nuts and bolts, bottlecaps).

The common element. These loosely related examples of direction of motion problems all have at least one element in common: All involve the operator's stereotypic frame of reference, or point of view. In the current investigation the issue takes a form not previously investigated, namely: How does a pilot's intervening internal representation of the meaning of symbols that vary in size as a function of altitude affect control/display motion compatibility? On the one hand, we can think of the symbology as representing surface objects that subtend decreasing visual angles as one ascends; or alternatively, one can think of the downward field of view that would be visible through a porthole (in this case octagonal) in the bottom of the aircraft.

## PROBLEM

The primary question is whether the HOVERING display's altimeter moves in the appropriate direction for optimum display/control motion compatibility. As previously mentioned, there are some engineering psychologists and pilots that have suggested that the display's presentation of altitude moves in the opposite direction to a pilot's expectation. There are reasonable arguments for both the current direction of motion and movement in the opposite direction. An experimental evaluation of the altimeter's direction of motion (DOM) was conducted to resolve this question. This evaluation involved the manipulation of relevant display and control system variables as well as the altimeter's direction of motion.

## ANALYSIS OF VARIABLES

### Experimental Variables

Direction of motion. In this experiment the two alternative directions of motion of the octagonal altimeter and the vertical rate fields were varied independently. Currently the octagonal altitude symbol dilates (expands outward) when the vertical speed control is displaced upward and constricts when the vertical speed control is displaced downward. Correspondingly, the desired and actual vertical rate indicators move outward to indicate positive vertical rates and inward for negative vertical rates. Manipulation of the vertical rate-field indicators was also included to test for interactions with other control and display variables. Qualitative by nature, the four combinations of DOM of the altimeter and vertical rate-field indicators were compared.

Control order. In this experiment control order was the single control variable manipulated. Several different studies have shown that control order affects tracking performance significantly (e.g., Roscoe and Kraus, 1973; Poulton, 1974). The order of control is determined by the number of times an input signal is integrated to result in the desired output (Roscoe, 1980). The relationships between the indices of desired performance and actual aircraft control are not easily integrated. Therefore, it is desirable to reduce the pilot's task to second-order or possibly first-order control (or some combination thereof). In a first-order system a given input will result in a specific velocity, whereas a given input in a second-order system will command a given acceleration to the controlled object.

### Fixed Parameters

Control gain reduction. With respect to the HOVERING display's altitude presentation, there would be a high degree of variability in control/display ratios associated with changes in altitude scales if not compensated for in some way. When the pilot ascends through the 60-foot scale, the altitude scale limits are changed to 250 feet (Figure 4). As the pilot ascends through the 250-foot scale, the altitude scale limits are changed to 1000 feet, and then 4000 feet. Conversely, as the pilot descends, the 4000-foot scale is replaced by the 1000-foot scale at 1000 feet; and so it goes to the 250-foot scale and then the 60-foot scale.

Each time the scale limit decreases (increasing the scale factor), the display sensitivity is increased. This would cause an abrupt change in control/display ratio if control gain were held constant. Sudden reductions in display sensitivity will result in undercontrolling by the pilot, and sudden increases will cause instability if not compensated for by associated changes in control gain or by some other adjustment. To deal with this problem, a gain reduction logic is programmed to decrease control gain by about one-half (specifically 0.545) each time the altitude scale factor increases. Pilots readily adjust to the remaining changes in control/display ratio (Tatro et al., 1983; Tatro and Roscoe, 1985).

Prediction time. During development of the HOVERING display it was determined that a vertical flight-path predictor should be added to the display (Tatro and Roscoe, 1985). The predictor provides an approximate indication of where the vehicle will be at some time in the future based on current control inputs. Results of prediction time studies have shown this parameter to be an important system variable, but the results are inconsistent. Some results indicate that longer prediction times are favorable, whereas others favor shorter prediction times (Poulton, 1957; Kelley, 1962; Roscoe, 1980). For this experiment, a fixed prediction time of two seconds was selected, based on pretest evidence that less experienced subjects benefit from prediction times longer than those investigated by Tatro.

Prediction order. The order of the vertical flight-path predictor refers to the number of integration terms included in the computation. Essentially, it determines the accuracy of the predictor; the more integration terms included (i.e., higher-order prediction), the more accurate the predictor, but the performance benefits from including higher than second-order terms are slight. Based on performance values previously determined by Tatro et al. (1983), a second-order computation was chosen for this experiment.

## Task and Subject Variables

In addition to the fixed levels of prediction time, prediction order, and control gain reduction ratio; the two levels each of altitude and rate-field direction of motion; and the four levels of control order, there were four tasks (flight scenarios) and four levels of subject ability based on a pretest, both of which will be described. Thus the experiment involved a 2 x 2 x 4 x 4 x 4 matched-subjects design, to be described in the METHOD section.

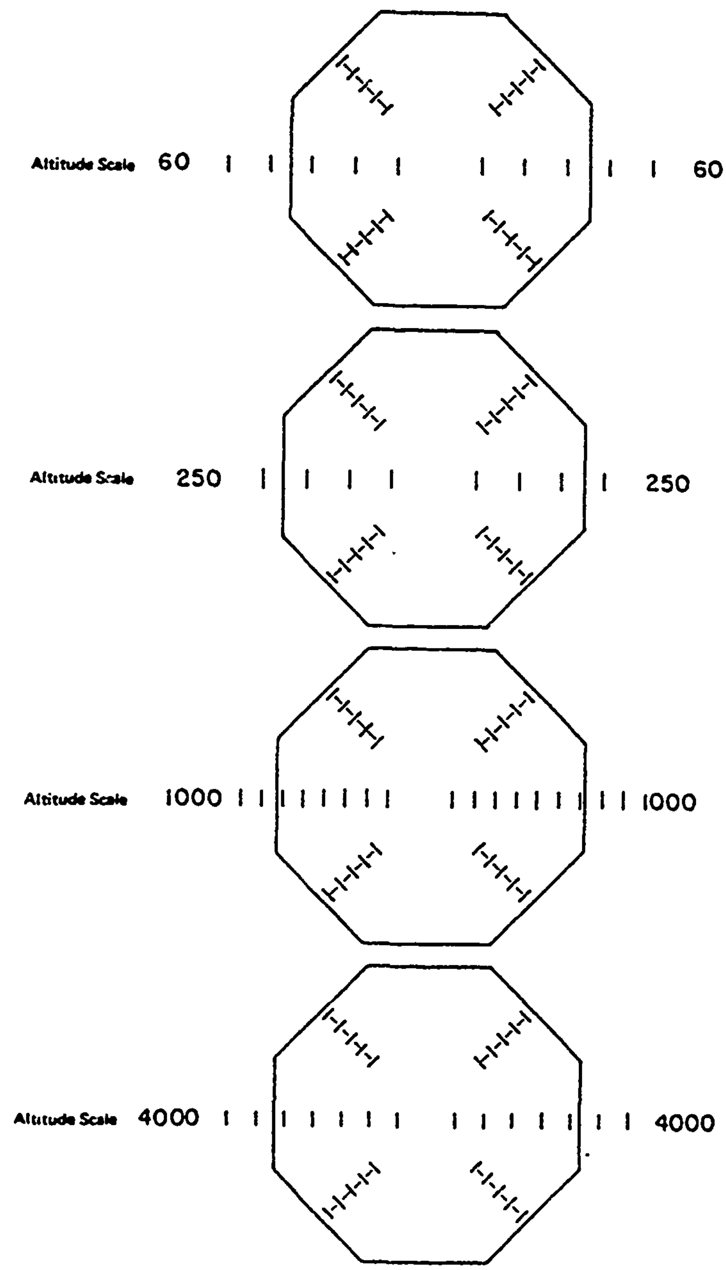


Figure 4. Example of altitude scale changes in the HOVERING display (Tatro et al., 1983).

## METHOD

### Design Considerations

Counterbalancing the sequences of presentation of experimental conditions across subjects is routinely done as a means of neutralizing intraserial learning and fatigue effects in within-subject experiments. However, conventional counterbalancing does not serve this purpose well when there is asymmetrical transfer among the various experimental treatments (Poulton, 1974). Asymmetrical transfer (carryover effects from condition to condition) occurs when the transfer effect from, say, condition A to condition B is not the same as that from B to A. In such cases, counterbalancing will not neutralize intraserial effects and in fact will result in systematic bias.

There are several means of coping with the well-known problem of asymmetrical transfer in experiments involving control/display direction of motion variables. For example, Wiedemann, Tatro, and Roscoe (in preparation) showed that the unequal carryover between pursuit and compensatory tracking modes (initially present in their experiment, as expected; Poulton, 1974), was eliminated after the third day of training by the insertion of buffer trials to allow interference effects to dissipate before taking test data. Extended training and buffer trials may be practical in experiments involving only two treatments, but they quickly become prohibitive in multi-factor experiments, as does the alternative between-subjects approach recommended by Poulton.

### Experimental Design

A reasonably economical compromise is a matched-subjects design (Matlin, 1979) in which the experimental treatments having high probability of differential facilitation and interference effects are assigned individually to relatively small independent groups well-matched in initial ability. Experimental variables not likely to elicit assymmetrical intraserial effects are then manipulated within the matched groups. The resulting data are analyzed as if the experiment were in fact a within-subject design. The matched individuals in the various independent groups are treated as if they were the same person. If the individuals at the various "ability levels" in the different groups are indeed well matched, the statistical benefits of correlated data will be the reward.

### Subject Matching

In the present experiment, four groups of four flight-naive male subjects each were matched on the basis of pretest scores on a time-shared tracking and digit-cancelling test developed by the USAF Human Resources Laboratory. Initially 20 potential subjects were tested using a portable basic attributes testing (Porta-BAT) system developed by ILLIANA Aviation Sciences for AFHRL. Subjects were trained and tested over a series of ten 90-second trials followed by five series of five trials each during which they approached their individual asymptotic performance levels. An "ability level" for each subject was based on the means for the best three consecutive trials in each series.

To match the groups for the four direction of motion treatments, 16 of the original 20 subjects were selected to form four stratified ability levels with relatively large differences in average ability between levels and relatively small variability within any level. The assignment of one subject from each level to each direction of motion treatment, as shown in Table 1, served to reduce the experimental bias inevitably associated with random assignment to treatments in conventional between-subjects designs (Simon and Westra, 1984). In the within-subject portion of the design each subject was tested on four counterbalanced levels of control order over four counterbalanced vertical-course sequences, as shown in Tables 2 and 3.

Flight Task

The four flight scenarios selected for this experiment simulated variations of a 35-second, point-to-point, terrain following and avoidance task. The command vertical-flight profile was limited between 0 feet and 200 feet. These limits were chosen so the pilot would experience an altitude scale change when crossing the 60-foot limit. For each level of control order, half of the trials involved scale changes (either ascending or descending through the 60-foot level), and half of the trials did not. The task began in level flight at an altitude of 100 feet, then desired altitude increased or decreased, returned to level flight, then increased or decreased and returned to level flight (see Figure 5).

To induce a realistically elevated workload, subjects were required to perform a secondary translational tracking task as well as the primary vertical tracking task. The side task began with a five-second cruise at 200 knots, followed by a turn (half of the trials to the right and half to the left) at a rate of one degree per second, for ten seconds. Subjects again cruised for five seconds, followed by a turn in the opposite direction of the first, at a rate of one degree per second, for ten seconds. Subjects then completed the trial with a five-second cruise at 200 knots.

Performance Measures

When conducting an analysis of variance, a normal distribution of scores is assumed. When scores are not normally distributed, they should be appropriately transformed before computing normal probability statistics. The theoretical distribution of RMS errors is in accordance with the chi-square distribution, and for sample sizes typically obtained in tasks similar to the present one, a logarithmic transformation is the empirically supported choice (Tatro et al., 1983). This transformation consistently yields a

Table 1

Subject Matching by Ability Level into DOM Treatment Groups

| DOM Treatment | | Ability Level | | | | |
|---|---|---|---|---|---|---|
| Altimeter | Rate Fields | 1 | 2 | 3 | 4 | Mean |
| Out/Down | Out/Down | 420 | 370 | 345 | 276 | 353 |
| Out/Down | Out/Up | 443 | 379 | 320 | 290 | 358 |
| Out/Up | Out/Up | 410 | 387 | 346 | 289 | 358 |
| Out/Up | Out/Down | 408 | 402 | 364 | 278 | 363 |

Table 2

Control Order by Session for All DOM Treatment Groups on Each Day

| Ability Level | Control Order by Session | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 (Mean = 420) | 1.00 | 1.75 | 1 25 | 1.50 |
| 2 (Mean = 384) | 1.25 | 1.00 | 1.50 | 1.75 |
| 3 (Mean = 344) | 1.50 | 1.25 | 1.75 | 1.00 |
| 4 (Mean = 283) | 1.75 | 1.50 | 1.00 | 1.25 |

Table 3

Counterbalanced Sequences of Presentation of the Four Vertical Courses to the Four Subjects in Each DOM Treatment Group During Each 16-Trial Session Each Day

| Ability Level | Courses by Trials | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 (Mean = 420) | A | D | B | C | C | B | D | A | A | D | B | C | C | B | D | A |
| 2 (Mean = 384) | B | A | C | D | D | C | A | B | B | A | C | D | D | C | A | B |
| 3 (Mean = 344) | C | B | D | A | A | D | B | C | C | B | D | A | A | D | B | C |
| 4 (Mean = 283) | D | C | A | B | B | A | C | D | D | C | A | B | B | A | C | D |

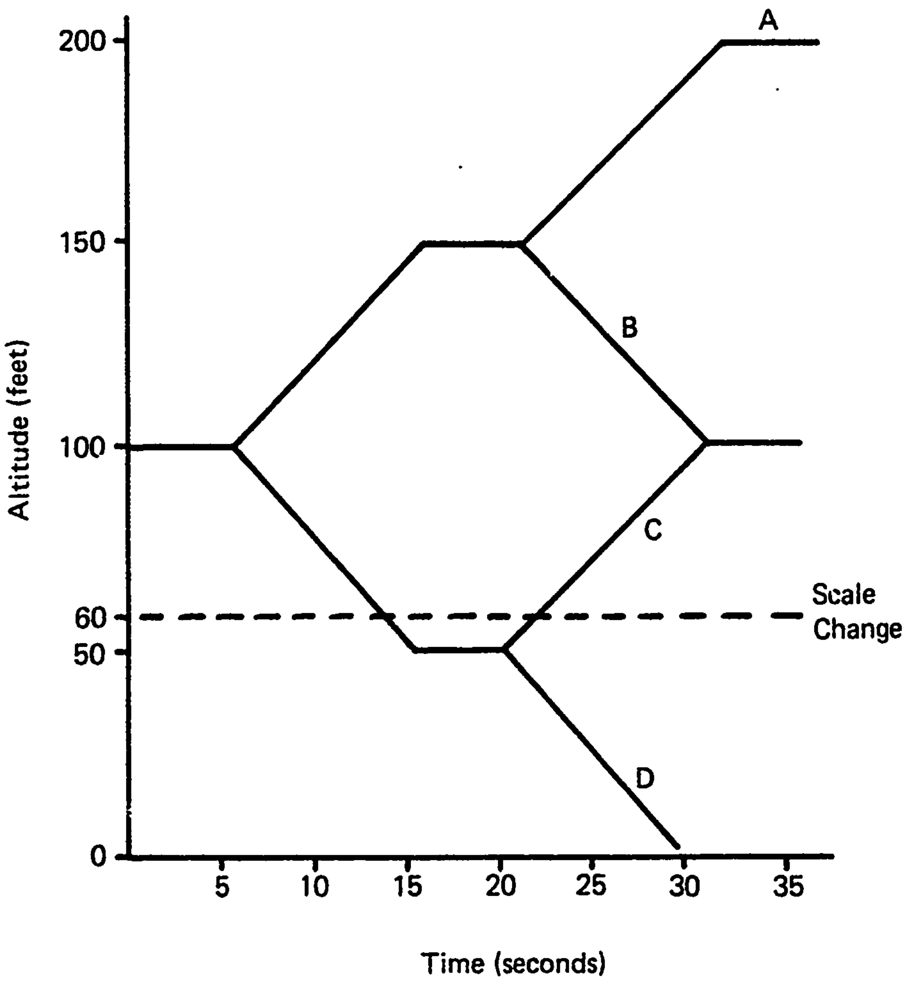


Figure 5. Vertical flight paths with the location of the scale change.

good approximation of a normal distribution and serves to homogenize the variances of the distributions for the different experimental treatments (VanderKolk and Roscoe, 1973).

As a second performance measure for the vertical dimension, the number of control reversals was scored. Control reversals have been defined in different ways by different investigators, but their essential characteristic is a persistent condition in which the control input serves to increase rather than reduce a positional error. For this experiment, "persistent" was defined as three-tenths of a second or more during which the vertical control was displaced in the wrong direction by an amount exceeding ten percent of the full stick displacement capability, relative to its position over the preceding four-tenths of a second.

## Procedure

Before beginning the experiment, subjects were given a 20-minute briefing on the HOVERING display, followed by two practice trials. The briefing instructions were designed to provide a different but equally logical rationale for each of the four direction of motion presentations flown by the four independent subject groups. These rationalizations were essentially repetitions of the respective explanations of the possible alternative points of view given previously. In one case the altimeter octagon was to be thought of as varying in size with the surface area that could be seen through a downward-looking porthole; in the other case, varying with the visual angles subtended by surface objects.

On each of two consecutive days subjects flew four 12-minute sessions with five-minute rest breaks between sessions. Each session consisted of sixteen 35-second trials with ten-second relaxation intervals between trials (16 x 45 = 720 seconds ÷ 60 = 12 minutes). All 16 trials were flown with the control-order specified for that subject on that session, as shown in Table 2. The particular course flown on a given trial was specified for that subject by the counterbalanced sequences shown in Table 3. Tables 2 and 3 apply to all DOM treatment groups. Following each trial, tracking error scores were displayed to the subject.

## RESULTS

Summaries of the analyses of variance, including significant main effects and first-order interactions and the associated cell means for each dependent measure, are presented in the APPENDIX. Significant second-order (three-way) interactions appeared in several analyses and are reported as such. However, the cell means for these interactions are not included in the tables because the interactions are beyond comprehensible interpretation. Selected main effects and first-order interactions to be described are shown graphically in Figures 6 through 11.

### Subject Abilities

Tracking performances on all three dependent measures bore a strong, direct relation to the pretest "ability" scores used to form the matched groups, as shown in Figure 6. A similar relation was found in terms of control reversals for ability Levels 2, 3, and 4, but one of the four subjects in Level 1 made a sufficient number of reversals to disrupt the general trend, as shown in Figure 7. Nevertheless, it was evident that use of a predictive covariate measure of this type in a matched-subjects design significantly reduced the experimental bias inevitably associated with random assignment of subjects to treatments (Simon and Westra, 1984).

### Mission Scenarios

The four different vertical courses elicited statistically reliable but numerically small differences in scores for each of the three log RMS performance measures, as shown in Table 4. Furthermore, the order of the scores differed from measure to measure with the result that the averages of the vertical, lateral, and longitudinal log RMS errors were virtually identical for the four courses. Thus it appears that the courses differed quantitatively only in terms of their tendency to elicit control reversals, with Course C (two altitude scale changes) eliciting the largest number of reversals and Course D (one scale change) the second largest number. Courses A and B had no scale change (Figure 5).

### Control Order

Variations in the order of vertical control between 1.00 and 1.75 had a statistically significant effect on vertical RMS error only and virtually no effect on translational control or the frequency of control reversals. As control order was reduced from 1.75 to 1.50 to 1.25 to 1.00, vertical RMS errors in feet decreased in an almost perfectly linear progression from 20.9 to 18.6 to 16.2 to 14.8, an overall reduction of almost 30 percent. Because this systematic effect was relatively independent of the levels of other experimental, task, or subject variables, there is no evident reason why pure first-order vertical control should not be adopted as a fixed parameter.

Table 4.

Relative Difficulty of the Four Vertical Courses as Reflected by the Various Performance Measures

| Performance Measure | Vertical Course A | B | C | D | Mean |
|---|---|---|---|---|---|
| RMS Error in Feet | | | | | |
| Vertical | 19.1 | 18.6 | 17.4 | 15.1 | 17.6 |
| Lateral | 26.3 | 27.5 | 33.1 | 33.1 | 30.0 |
| Longitudinal | 12.0 | 12.3 | 13.2 | 14.8 | 13.1 |
| Average RMSE | 19.1 | 19.5 | 21.2 | 21.0 | 20.2 |
| Control Reversals | 0.80 | 1.60 | 1.48 | 1.23 | 1.14 |

## Direction of Motion

The main effects and first-order interactions associated with the independent manipulation of the altimeter DOM (the size of the octogon) and the rate-field DOM (direction of flow) were statistically significant in every case, but were mixed in direction for the different dependent variables. Vertical control reversals and vertical log RMS tracking errors favored the original out/up altimeter DOM, whereas translational control yielded smaller error scores with the converse arrangement, all of which are shown graphically in Figures 8 and 9. The one consistent finding is that whichever altimeter DOM is used, the rate fields should flow in the same direction; in particular, the combination of altimeter out/down and rate fields out/up must be avoided.

The two DOM variables also interacted strongly with all other variables in terms of from one to all four performance measures. Most notably, in terms of control reversals, the altimeter DOM interacted with vertical courses, and the rate-fields DOM with subject ability levels, as shown in Figures 10 and 11, respectively. There were substantially fewer control reversals with the original out/up altitude DOM on all courses except D, in which case the converse was true. With the rate-fields DOM out/down, there were fewer control reversals by all ability levels except Level 2, for which there was a large difference in the opposite direction.

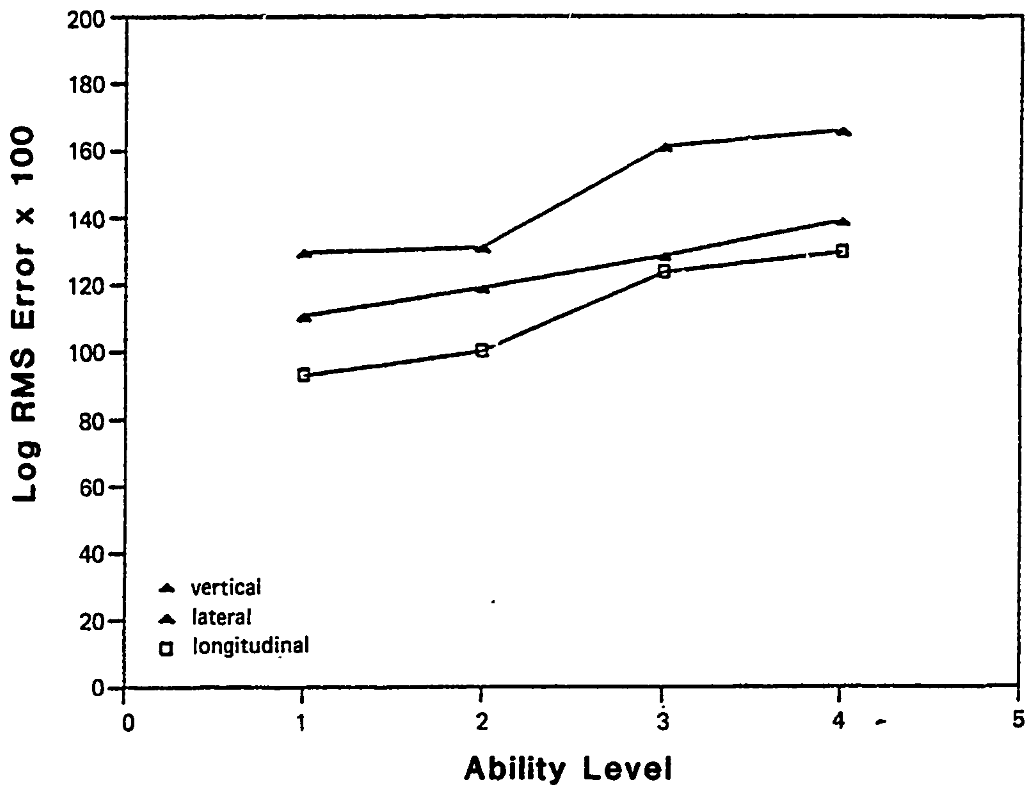


Figure 6. Longitudinal, vertical, and lateral log RMS error as a function of ability level.

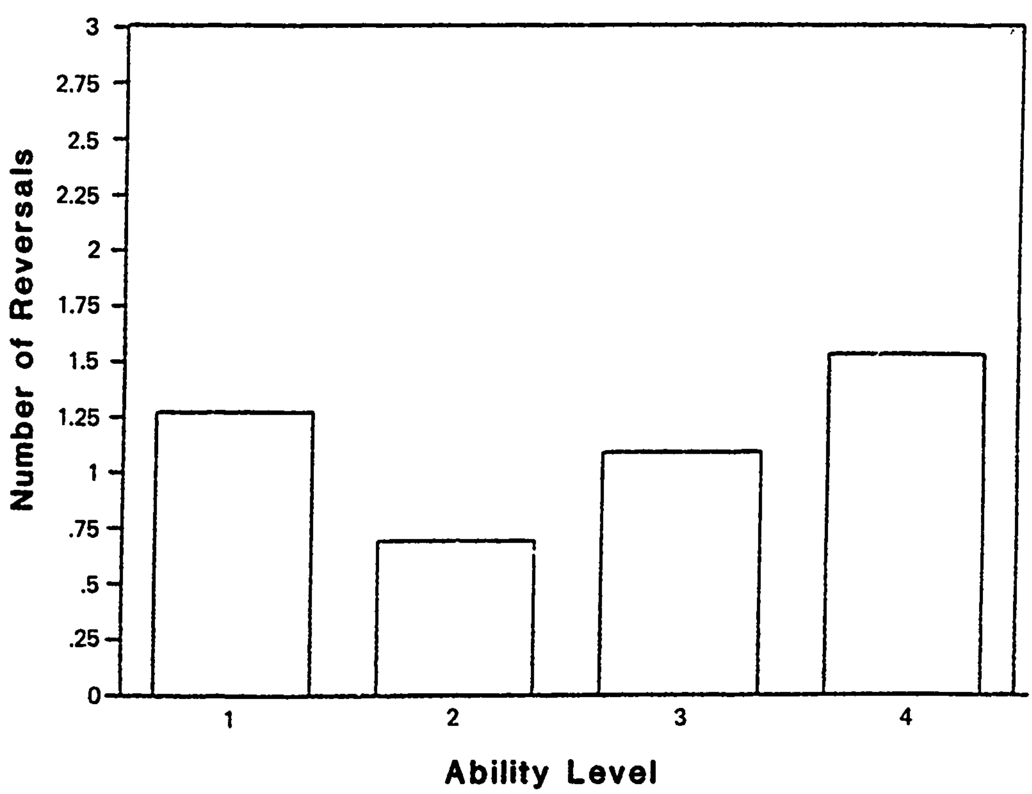


Figure 7. Mean number of control reversals per trial as a function of ability level.

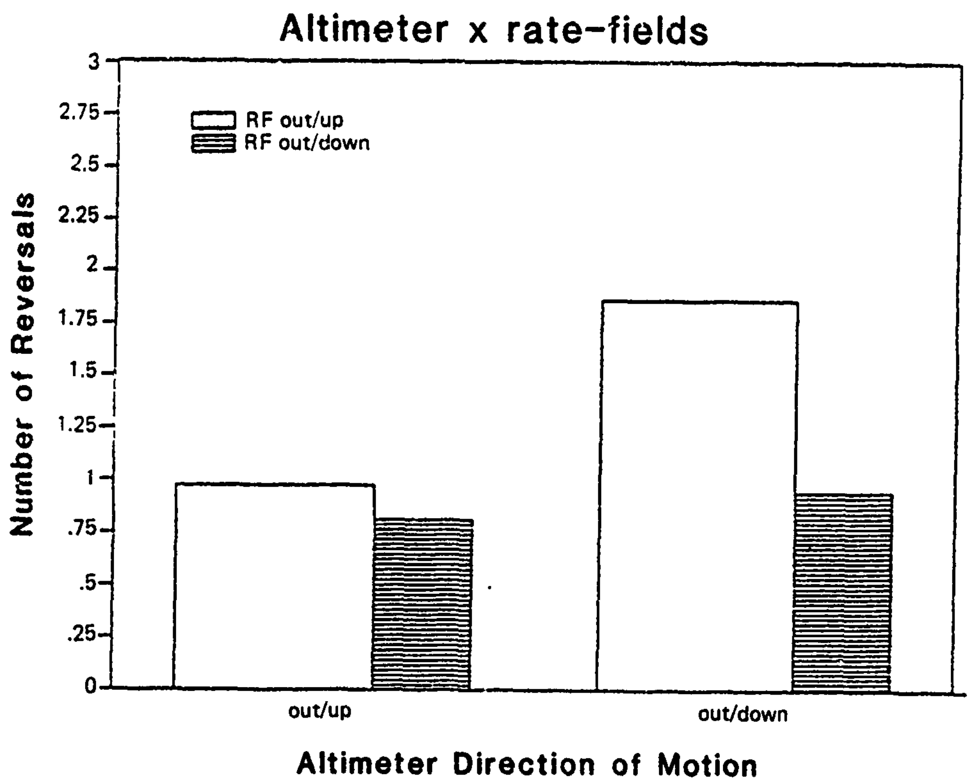


Figure 8. Mean number of control reversals per trial as a function of altimeter and rate-field direction of motion.

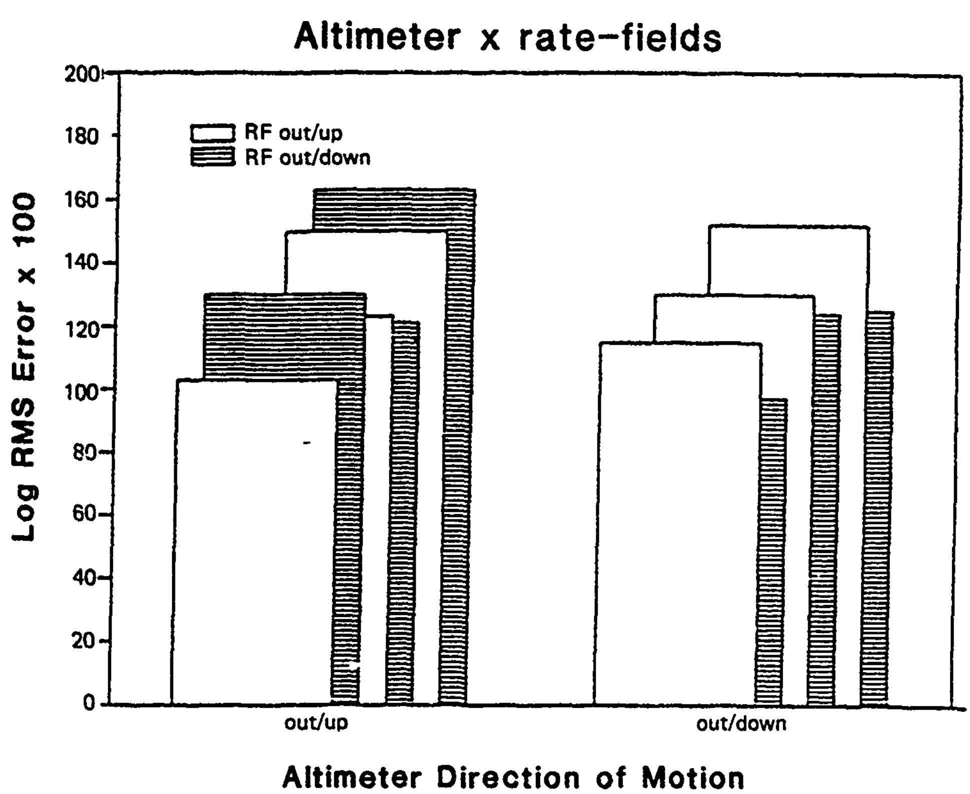


Figure 9. Moving from left to right, longitudinal, vertical, and lateral log RMS error as a function of altimeter and rate-field direction of motion.

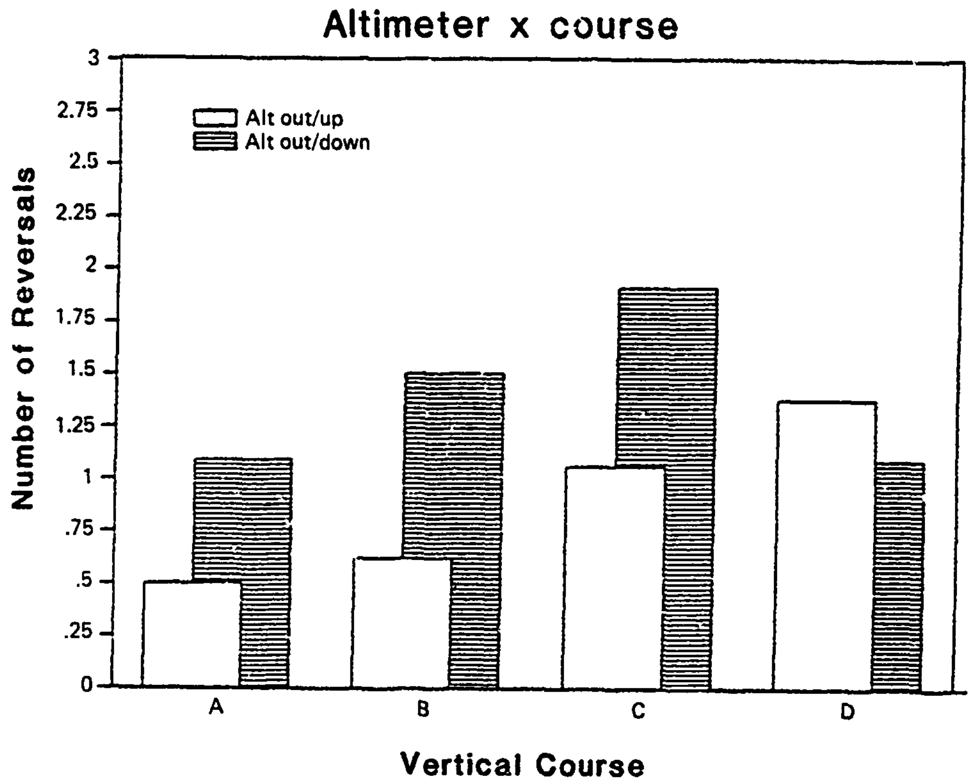


Figure 10. Mean number of control reversals per trial as a function of altimeter direction of motion and vertical course.

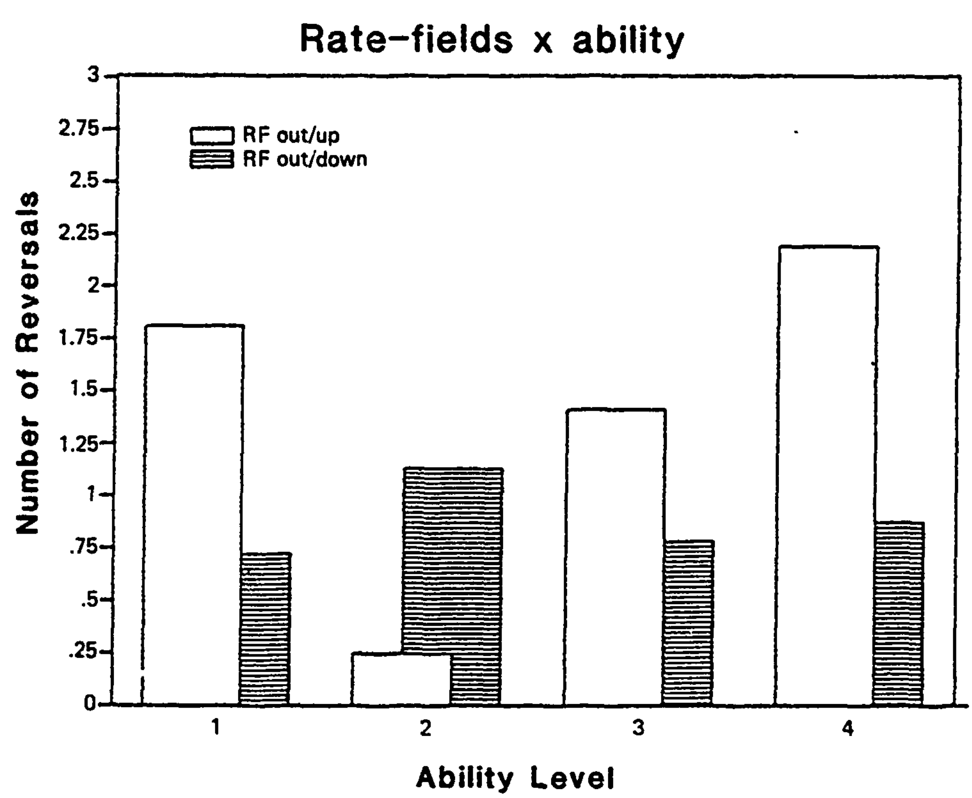


Figure 11. Mean number of control reversals per trial as a function of rate-field direction of motion and ability level.

## DISCUSSION

The issue of proper direction of motion of the altimeter and rate fields is a complicated one that interacts with various control and display system variables. The one consistent finding regarding this issue is that, whichever way the altimeter moves, the rate fields should move in the same direction. When the altimeter and rate fields move in opposite directions, control reversals are more frequent and tracking performance suffers. The data suggest that whether out/up or out/down motion is better depends on the performance measure considered, on the flying skill and time-sharing ability of the pilot, and very likely on the way pilots are trained to interpret the display.

Before considering more detailed implications of this experiment, a word is in order concerning their generalizability. Whenever stereotypic response tendencies are the object of investigation, the subject population is a critical consideration. For this initial study, flight-naive subjects were sampled. Hence, it would be risky and unwise to expect the same stereotypic response patterns from experienced pilots. However, because the HOVERING display is new to everyone and the dynamics of our generic VTOL simulation do not represent any specific real-world aircraft, we have observed informally that pilots, whatever their experience, require about the same amount of training as nonpilots to fly the simulator equally well.

The matching of subjects in stratified ability levels based on pretest scores on the USAF time-shared tracking and digit-cancelling test served its purpose well. Results indicate that overall tracking and time-sharing performance in terrain following and avoidance improved systematically with increasing initial ability scores. For all dependent measures, performance varied directly with initial ability, with the exception that one subject in the highest ability level made a disproportionately large number of reversals. Several interactions with ability were significant over all dependent measures.

Display and control system variables were manipulated in the vertical dimension only. For the secondary horizontal control task, display and control system parameters were fixed on the basis of pretest results or from prior evaluation (Tatro et al., 1983). A subsequent study by Wiedemann and Roscoe (1985) involving the most critical display and control system variables indicates that control order of 1.6 (mixed velocity and acceleration) is a near-optimum value for translational control, rather than the pure acceleration control used in the horizontal plane in this study.

The evident reason for the discrepancy between the optimum control orders found by Tatro et al. and by Wiedemann and Roscoe is because the latter investigators tested a wider range of control orders in combination with wider ranges of all other critical variables. Particularly in the more complex maneuvers included in two of Wiedemann and Roscoe's flight scenarios, pure acceleration control (second-order) became quite difficult to manage. The consequence of using pure acceleration translational control in the present experiment is that absolute performance levels in the horizontal dimension should not be generalized to systems optimized with respect to other design variables.

In this experiment, the secondary task was designed to create an elevated workload and to provide an inferential measure of the interactive effects of control and display system variables involved in the primary task. The results indicate that the secondary task served both purposes well. Vertical control, both in terms of control reversals and tracking performance, was better with the altimeter in the out/up configuration, whereas lateral and longitudinal tracking errors indicate that performance was better with the altimeter out/down.

These results suggest a time-sharing tradeoff between the two directions of motion. With the altimeter out/up, when pilots are tracking near the lower limit of a scale, the vertical goal bars constrict almost to a dot, as does the octagonal altimeter if the pilot is on target. Under this condition, much smaller errors can be detected and corrected than is the case when the symbol is dilated in the out/down mode. However, making these fine discriminations takes more attention from the secondary translational task with a consequent performance decrement in longitudinal and lateral control.

The time-sharing tradeoff between horizontal and vertical control is complicated further by the differences in scanning required in the out/up and out/down modes. In this experiment, the four vertical courses contained level flight altitudes of zero, 50, 100, 150, and 200 feet. Thus, in the out/up mode, the octagon ranged in size from almost a dot at zero feet to 5/6 of its fully dilated size at 50 feet on the 60-foot scale. Conversely, in the out/down mode, the octagon ranged from its fully dilated size at zero-feet to a minimum of 1/6 of its fully dilated size at 50 feet on the 60-foot scale.

So, by virtue of the level flight altitudes that happened to be chosen for this experiment, the octagon in the out/down mode was larger on average than it was in the out/up mode, and it only briefly reached its minimum possible size as it passed through the 60-foot/250-foot scale change (once on Course D and twice on Course C). As a consequence, the center of the display was somewhat less cluttered than it was in the out/up mode, and slightly more scanning was required between the secondary horizontal task and the primary vertical task. On balance, the out/up mode favored vertical control, and the out/down mode favored translational control.

Four vertical flight paths were used in this study. The four courses were designed to simulate maneuvers typical of those called for in terrain following and terrain avoidance missions. Tracking performances were inconsistent across the three log RMS measures, evidently because of the varying attentional demands imposed on the pilot over the different courses. Course C had two scale changes and one change in vertical direction, whereas course D had only one scale change, but the pilot was required to fly level at zero feet. Course B had a change in vertical direction, whereas course A had no changes in scale or direction (see Figure 5).

Flight tasks used in the Wiedemann and Roscoe (1985) study were takeoff, terrain following and landing, and the standard instrument departure used by Tatro et al. (1983). Results of that experiment indicate that optimum values for some display and control parameters vary as a function of the phase of a mission and also with changes in scale factor of the octagonal altimeter and in control gain as the aircraft ascends and descends. These results suggest that when conducting experiments one should evaluate the effects of the factors over several types of mission scenarios. By following this procedure the experimenter is able to obtain a clearer view of the effects of the critical factors.

Control order in the vertical dimension had a significant effect in the current study. Tracking performance improved as a function of decreasing levels of control order, with pure velocity control resulting in best performance over all courses. Missions involving terrain following and terrain avoidance require that the pilot constantly make vertical and horizontal control manipulations. First-order control results in best performance for this type of task. At this low order of control, the vehicle responds to control inputs quicker, and pilots have less tendency to overcontrol, both of which are highly desirable for terrain following tasks.

Because the flight tasks were different, no direct comparison can be made between the absolute levels of tracking performance in this experiment and the earlier experiment by Tatro et al. (1983). However, on a relative basis, in the earlier experiment vertical tracking error (RMSE = 37 feet) was about twice as large as lateral or longitudinal error (15 and 18 feet, respectively). In the present experiment, vertical error (RMSE = 18 feet) was appreciably smaller than lateral error (30 feet) and only slightly larger than longitudinal error (13 feet), as shown in Table 4. The evident reason for the relative improvement in vertical tracking was the incorporation of the vertical flight-path predictor symbols not present in the earlier experiment.

The results of this experiment bear only indirectly on the original theoretical question concerning the relationships among (1) the direction of vertical control inputs, (2) the pilot's internal representation of vehicle responses in an earth-referenced versus vehicle-referenced context, (3) the increasing or decreasing size of a display symbol representing altitude, and (4) the dilating or constricting flow of rate fields indicating speeds of vertical transition. The lack of consistent differences favoring either "out is up" or "out is down" suggests that there is no stereotypic relationship between symbol size, direction of control inputs, and internal representation of the frame of reference, so long as symbol size and direction of rate-field flow are consistent.

Because this experiment involved only the downward-looking HOVERING display, its compatibility with a computer-animated contact analog display or a direct view of the outside world was not addressed. Thus, the preferred direction of motion for the altimeter octagon may depend on these and other considerations not yet investigated, particularly ones associated with the future incorporation of additional display functions, map detail, and both forward- and downward-looking sensor imagery. In whatever way such developments may affect the direction of motion question, the evident superiority of the HOVERING display over other attempts at integrating the information required for vertical and translational flight control should not be lost.

# APPENDIX

## SUMMARIES OF ANALYSES OF VARIANCES

Table A-1

Summary of Analysis of Variance for Number of Control Reversals

| Source of variance: | | df | f |
|---|---|---|---|
| Altimeter: | out/up(+) vs out/down(-) | 1 | 11.02** |
| Rate-fields: | out/up(+) vs out/down(-) | 1 | 12.43** |
| Ability: | 1 vs 2 vs 3 vs 4 | 3 | 5.46* |
| Control Order | 1.00 vs 1.25 vs 1.50 vs 1.75 | 3 | .44 |
| Course: | A vs B vs C vs D | 3 | 3.53* |
| Reliable interactions: | | | |
| Altimeter X rate-fields | | 1 | 6.20* |
| Altimeter X course | | 3 | 3.15* |
| Rate-fields X ability | | 3 | 10.57** |
| Ability X rate-fields X altimeter | | 3 | 8.23** |

Cell means and effects:

Altimeter DOM:

| + | - |
|---|---|
| 0.89 | 1.40 |

There were fewer control reversals with the out/up direction of motion.

Rate-fields DOM:

| + | - |
|---|---|
| 1.41 | 0.87 |

There were fewer control reversals with the out/down direction of motion.

Ability level:

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 1.27 | 0.69 | 1.09 | 1.53 |

The frequency of control reversals varied irregularly among the four ability levels.

Course:

| A | B | C | D |
|---|---|---|---|
| 0.80 | 1.06 | 1.48 | 1.23 |

The frequency of control reversals differed among the four courses, with the least for A and the most for C.

* probability $< .05$

** probability $< .01$

(Table A-1 continued)

Altimeter X rate-fields:

| | + | - | |
|---|---|---|---|
| | | | There was a disproportionately large number of control reversals |
| + | 0.97 | 0.81 | when Alt DOM out/down was paired |
| - | 1.86 | 0.94 | with RF out/up. |

Altimeter X course:

| | A | B | C | D | |
|---|---|---|---|---|---|
| | | | | | There were fewer control reversals with Alt DOM out/up for all |
| + | 0.50 | 0.62 | 1.06 | 1.38 | courses except D, where the |
| - | 1.09 | 1.50 | 1.91 | 1.09 | converse was true. |

Rate-fields X ability:

| | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| | | | | | There were fewer control reversals with RF DOM out/down for all |
| + | 1.81 | 0.25 | 1.41 | 2.19 | ability levels except 2, where the |
| - | 0.72 | 1.13 | 0.78 | 0.87 | converse was true. |

Table A-2

<u>Summary of Analysis of Variance for Vertical Log RMS Error</u>

| Source of variance: | | df | f |
|---|---|---|---|
| Altimeter: | out/up(+) vs out/down(-) | 1 | 13.38** |
| Rate-fields: | out/up(+) vs out/down(-) | 1 | 8.36** |
| Ability: | 1 vs 2 vs 3 vs 4 | 3 | 69.21** |
| Control order: | 1.00 vs 1.25 vs 1.50 vs 1.75 | 3 | 21.82** |
| Course: | A vs B vs C vs D | 3 | 10.35** |
| **Reliable interactions:** | | | |
| Altimeter X ability | | 3 | 43.34** |
| Altimeter X course | | 3 | 4.53** |
| Rate-fields X ability | | 3 | 47.06** |
| Rate-fields X control order | | 3 | 4.05** |
| Rate-fields X course | | 3 | 5.20** |
| Ability X course | | 9 | 2.84* |
| Ability X rate-fields X altimeter | | 3 | 122.29** |
| Ability X control order X rate-fields | | 9 | 2.26* |
| Course X rate-fields X altimeter | | 3 | 2.95* |
| Course X ability X rate-fields | | 9 | 2.30* |

Cell means and effects:

Altimeter DOM:

| + | - |
|---|---|
| 122 | 127 |

Vertical tracking was better with the out/up direction of motion.

Rate-fields DOM:

| + | - |
|---|---|
| 126 | 123 |

Vertical tracking was better with out/down direction of motion.

Ability level:

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 111 | 119 | 128 | 139 |

Vertical tracking improved as initial ability increased.

* Probability < .05
** Probability < .01

(Table A-2 continued)

| | | | | | |
|---|---|---|---|---|---|
| Control order: | | | | | |
| | 1.00 | 1.25 | 1.50 | 1.75 | Vertical tracking improved with decreasing orders of control. |
| | 117 | 121 | 127 | 132 | |
| Course: | | | | | |
| | A | B | C | D | Vertical tracking performance differed among the four courses, with D proving the easiest. |
| | 128 | 127 | 124 | 118 | |
| Altimeter X ability: | | | | | |
| | 1 | 2 | 3 | 4 | Performance was better with Alt DOM out/up for all ability levels except 1, where the converse was true. |
| + | 122 | 110 | 127 | 129 | |
| - | 100 | 128 | 130 | 148 | |
| Altimeter X course: | | | | | |
| | A | B | C | D | With Alt DOM out/down, performance was disproportionately bad on course A; with Alt DOM out/up, performance was disproportionately good on course D. |
| + | 124 | 128 | 124 | 112 | |
| - | 132 | 127 | 124 | 124 | |
| Rate-fields X ability: | | | | | |
| | 1 | 2 | 3 | 4 | For ability levels 1 and 2, performance was better with RF DOM out/down; for ability levels 3 and 4, the converse was true. |
| + | 114 | 134 | 122 | 134 | |
| - | 109 | 104 | 134 | 143 | |
| Rate-fields X control order: | | | | | |
| | 1.00 | 1.25 | 1.50 | 1.75 | With RF DOM out/up, performance deteriorated more with increasing control order than it did with RF DOM out/down. |
| + | 117 | 124 | 126 | 137 | |
| - | 117 | 119 | 127 | 127 | |

(Table A-2 continued)

Rate-fields X course:

| | A | B | C | D |
|---|---|---|---|---|
| + | 127 | 127 | 128 | 123 |
| - | 129 | 128 | 120 | 113 |

With RF DOM out/up , performance differed little among courses; with RF DOM out/down, there were relatively large differences among courses.

Ability X course:

| | A | B | C | D |
|---|---|---|---|---|
| 1 | 114 | 114 | 113 | 105 |
| 2 | 124 | 121 | 115 | 118 |
| 3 | 127 | 138 | 130 | 118 |
| 4 | 147 | 137 | 138 | 132 |

For ability level 1, performance was disproportionately good on course D, and for ability level 4 it was disproportionately bad on course A.

Table A-3

Summary of Analysis of Variance for Lateral Log RMS Error

| Source of variance: | | df | f |
|---|---|---|---|
| Altimeter: | out/up(+) vs out/down(-) | 1 | 106.36** |
| Rate-fields: | out/up(+) vs out/down(-) | 1 | 12.84** |
| Ability: | 1 vs 2 vs 3 vs 4 | 3 | 108.61** |
| Control Order | 1.00 vs 1.25 vs 1.50 vs 1.75 | 3 | .67 |
| Course: | A vs B vs C vs D | 3 | 8.02** |
| Reliable interactions: | | | |
| Altimeter X rate-fields | | 1 | 119.67** |
| Altimeter X ability | | 3 | 43.08** |
| Altimeter X control order | | 3 | 4.39** |
| Rate-fields X ability | | 3 | 15.83** |
| Ability X rate-fields X altimeter | | 3 | 67.60** |
| Course X rate-fields X altimeter | | 3 | 3.50* |

Cell means and effects:

Altimeter DOM:

| + | - |
|---|---|
| 157 | 138 |

Lateral tracking was better with the out/down direction of motion.

Rate-fields DOM:

| + | - |
|---|---|
| 151 | 144 |

Lateral tracking was better with the out/down direction of motion.

Ability level:

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 130 | 132 | 161 | 166 |

Lateral tracking improved as initial ability increased.

Course:

| A | B | C | D |
|---|---|---|---|
| 142 | 144 | 152 | 152 |

Lateral tracking error differed among the four courses, with A and B proving easier than C and D.

* probability < .05
** probability < .01

(Table A-3 continued)

Altimeter X rate-fields:

| | + | - | |
|---|---|---|---|
| | | | With RF DOM out/up, Alt DOM has no differential effect, with RF DOM out/down, Alt DOM has a large differential effect. |
| + | 150 | 163 | |
| - | 152 | 125 | |

Altimeter X ability:

| | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| | | | | | Performance was better with Alt DOM out/down for all ability levels except 4, where the converse was true. |
| + | 134 | 145 | 185 | 163 | |
| - | 127 | 120 | 136 | 170 | |

Altimeter X control order:

| | 1.00 | 1.25 | 1.50 | 1.75 | |
|---|---|---|---|---|---|
| | | | | | With Alt DOM out/down, performance tended to improve with increasing control order; with Alt DOM out/up, the converse tended to be irregularly true. |
| + | 152 | 158 | 154 | 162 | |
| - | 140 | 141 | 139 | 133 | |

Rate-fields X ability:

| | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| | | | | | Performance was better with RF DOM out/down for all ability levels except 2, where the converse was true. |
| + | 138 | 126 | 163 | 176 | |
| - | 122 | 139 | 158 | 157 | |

Table A-4

Summary of Analysis of Variance for Longitudinal Log RMS Error

| Source of variance: | | df | f |
|---|---|---|---|
| Altimeter: | out/up(+) vs out/down(-) | 1 | 45.57** |
| Rate-fields: | out/up(+) vs out/down(-) | 1 | 9.57** |
| Ability: | 1 vs 2 vs 3 vs 4 | 3 | 127.86** |
| Control Order | 1.00 vs 1.25 vs 1.50 vs 1.75 | 3 | 1.93 |
| Course: | A vs B vs C vs D | 3 | 7.08** |
| Reliable interactions: | | | |
| Altimeter X rate-fields | | 1 | 197.67** |
| Altimeter X ability | | 3 | 70.62** |
| Rate-fields X ability | | 3 | 13.14** |
| Rate-fields X control order | | 3 | 5.73** |
| Ability X rate-fields X altimeter | | 3 | 84.49** |
| Ability X control order X rate-fields | | 9 | 2.29* |

Cell means and effects:

Altimeter DOM:

| + | - |
|---|---|
| 116 | 106 |

Longitudinal tracking was better with out/down direction of motion.

Rate-fields DOM:

| + | - |
|---|---|
| 109 | 114 |

Longitudinal tracking was better with the out/up direction of motion.

Ability level:

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 93 | 100 | 123 | 129 |

Longitudinal tracking improved as initial ability increased.

Course:

| A | B | C | D |
|---|---|---|---|
| 108 | 109 | 112 | 117 |

Tracking error differed among the four courses, with A and B proving easier than C and D.

* probability < .05
** probability < .01

(Table A-4 continued)

Altimeter X rate-fields:

| | + | - | |
|---|---|---|---|
| | | | Performance with either Alt DOM was better when RF DOM was the same. |
| + | 103 | 130 | |
| - | 115 | 97 | |

Altimeter X ability:

| | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| | | | | | With Alt DOM out/up, performance was disproportionately bad for ability level 3. |
| + | 92 | 103 | 147 | 124 | |
| - | 93 | 97 | 99 | 135 | |

Rate-fields X ability:

| | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|
| | | | | | With RF DOM out/up, performance were disproportionately good for ability levels 2 and 3 relative to their performances with RF DOM out/down. |
| + | 96 | 92 | 117 | 131 | |
| - | 90 | 108 | 129 | 127 | |

Rate-fields X control order:

| | 1.00 | 1.25 | 1.50 | 1.75 | |
|---|---|---|---|---|---|
| | | | | | Performances were better with RF DOM out/up for all control orders except 1.25, where the converse was true. |
| + | 106 | 116 | 106 | 108 | |
| - | 115 | 110 | 112 | 118 | |

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